Short-Crested Breaking Waves and Vorticity

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LONG-TERM GOAL

The long-term goal is to determine the contribution of short-crested breaking waves to vorticity (and thus mixing) in nearshore regions and near strong flows from inlets or river mouths.

OBJECTIVES

The objectives of our research in FY12 were:

- analyze field observations to determine the magnitude and variation of surfzone vorticity,
- determine if individual breaking waves generate vorticity, and
- obtain remote observations of breaking waves near the mouth of New River Inlet, NC, and begin analysis of breaking crest lengths.

APPRAOCH

Our approach is to develop new field methods and instrumentation to enable measurements of the processes affecting vorticity, and to assess the importance of those physical processes to numerical models of the nearshore region.

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WORK COMPLETED

1) *Analysis of surfzone vorticity data*
The first direct measurements of vorticity in the surfzone were made with a newly developed circular array of current meters. By combining the array data with remote imaging, vorticity in the surfzone was shown to be associated with breaking of individual short-crested waves.

2) *Field observations of breaking crest length*
High-resolution wide-angle images of breaking waves in the surfzone were acquired at New River Inlet and Duck, NC (Fig. 1). The images will be used to measure the distribution of breaking crest-lengths over a range of wave and tide conditions.

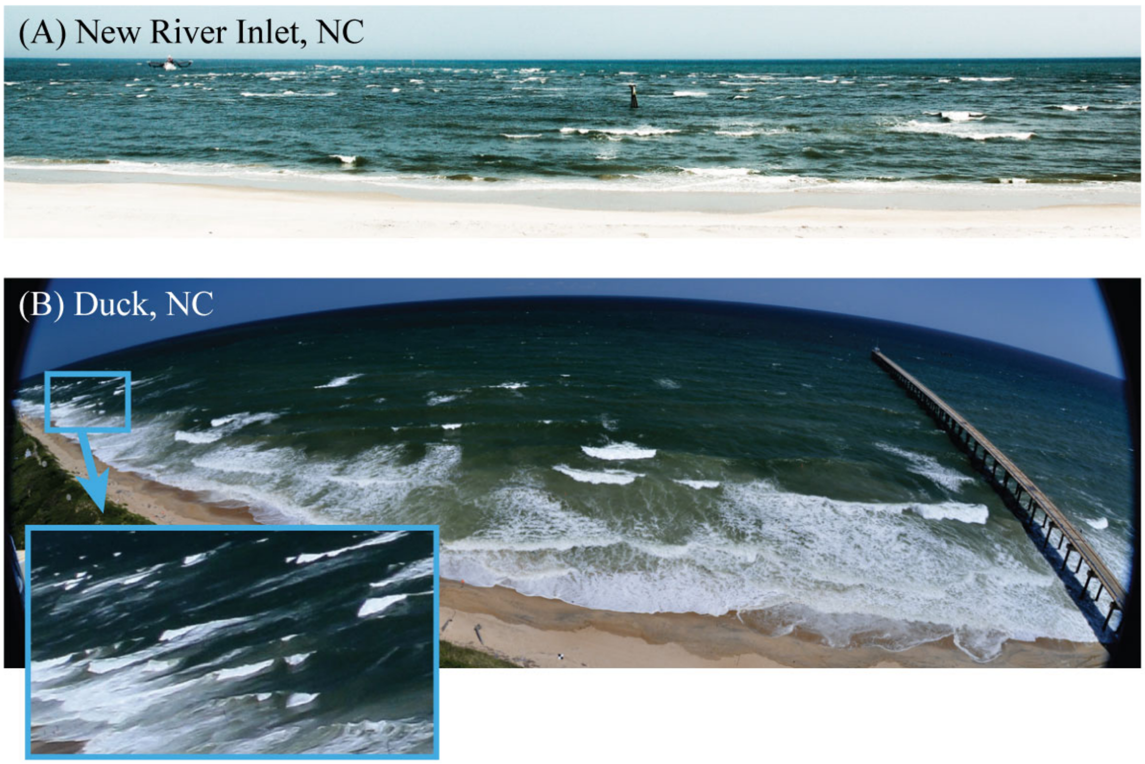

Fig. 1. Unrectified images taken at (A) New River Inlet and (B) Duck, NC. The 36-megapixel ultra-wide angle images (e.g., panel B) allow large sections of the nearshore to be observed with a single image, while resolving small-scale features (e.g., inset in blue rectangle in panel B). Rectification and image processing to measure the lengths of the breaking crests are part of our ongoing work. [Photographs of waves breaking on the ebb shoal of New River Inlet and along the shoreline at Duck, NC. The inset shows details of individual breaking waves a few hundred meters from the camera.]

RESULTS

We analyzed 12 hours of data from a novel circular array of current meters and obtained the first direct estimates of surfzone vorticity (i.e., horizontal eddies). The offshore waves had a mean angle of incidence near zero, but were directionally spread, and mean alongshore currents were weak. The observed vorticity had large variations on a range of timescales, but the mean vorticity was near zero (Fig. 2).

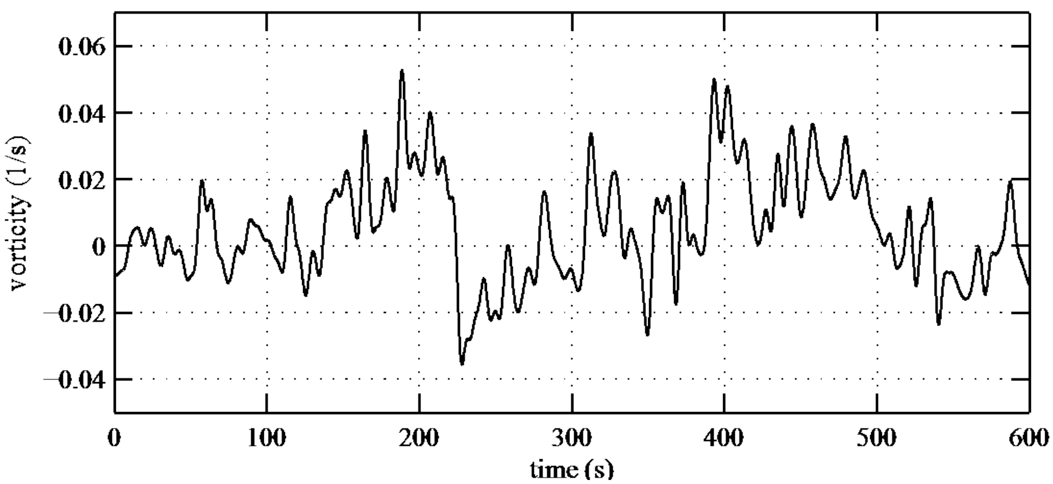

Fig. 2. Vorticity versus time. This is an example from the first vorticity time series measured in the surfzone. The variation in vorticity is indicative of the large scale (> 10 m) eddies thought to be a primary source of surfzone mixing. [Vorticity ranges from -0.04 to 0.05 s^{-1}, about a mean value of close to 0 over the 600 seconds shown.]

Video observations were used to isolate times when short-crested waves were breaking within or near the array. The vorticity generated by a breaking wave, $\Delta\omega$, is estimated from the vorticity before and after the breaking event

$$\Delta\omega = \omega(t_0 + \Delta t) - \omega(t_0) ,$$

where $\omega(t_0)$ is the vorticity just before the breaking event and $\omega(t_0 + \Delta t)$ is the vorticity Δt later. The vorticity generated by short-crested breaking varies throughout the tidal cycle, with the greatest vorticity generated near low tide and the least vorticity generated near high tide (Fig. 3). In agreement with theory, right- and left-handed waves generate negative and positive vorticity respectively, and the right- and left-handed vorticity magnitudes have similar variations in time (Fig. 3). Short-crested waves are expected to generate vorticity variation, but not mean vorticity for the normally incident and directionally spread conditions observed here. The short-crested vorticity has a similar magnitude to the total vorticity standard deviation (especially at low tides), and indicates that short-crested waves are a significant source of vorticity in the surfzone.

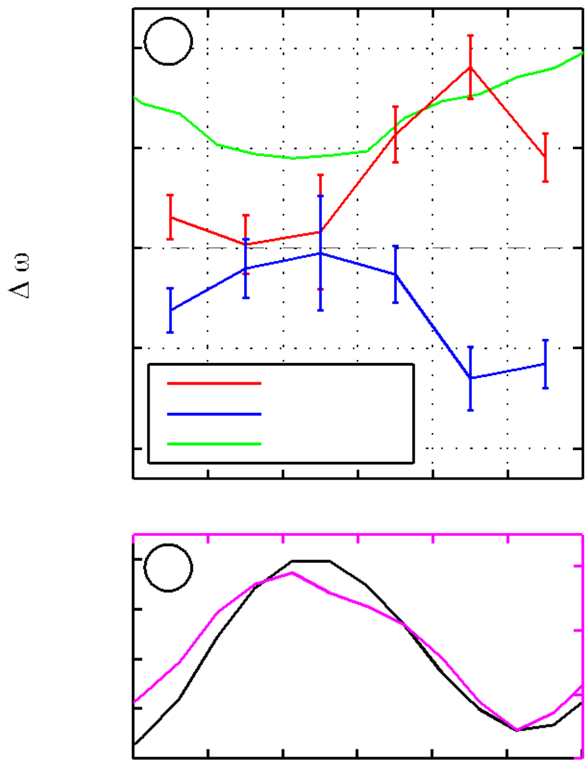

Fig. 3. (A) Vorticity generated by (red) left- and (blue) right-handed crest ends, and the total vorticity standard deviation versus time. (B) Depth and significant wave height versus time. [Left- and right-handed vorticity are small during high tide, and increase to greater than +/- 0.02 s^{-1} during low tide. The standard deviation ranges from 0.01 (low tide) to 0.02 s^{-1} (high tide). The tidal range was 0.8 m and wave heights ranged from 0.5 to 0.7 m.]

The spatial and temporal structure of vorticity generated by short-crested breaking is explored by averaging waves during low tides (maximal vorticity generation), combining left-handed vorticity with the negative of right-handed vorticity, and sorting waves by the alongshore position of the array relative to the crest-end. There is a rapid increase in vorticity at all measurement locations within the breaking region just after the breaking event (Fig. 4), with the maximum vorticity generated 5 m inside the breaking region. The vorticity generation 10 and 15 m within the crest is not predicted by theory, and may result from onshore advection of vorticity from previous stages of breaking or from the shape of the breaking region. The breaking-shape hypothesis is being investigated.

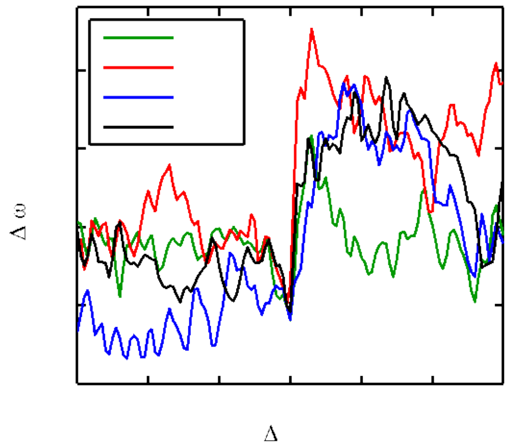

Fig. 4. Vorticity generated by short-crested waves at three locations within the breaking region (see legend) as a function of time from the breaking event ($\Delta t = 0$ s). [Vorticity rises rapidly ($\Delta t = 5$ s) to 0.018 s^{-1} at 5 m from the crest end, and rises more slowly (10-20 s) 10-15 m from the crest end, before slowly (40-60 s) falling to near zero.]

IMPACT / APPLICATIONS

We have made the first observations of vorticity generated by short-crested breaking waves, and validated a hypothesis formed more than 15 years ago. Our results indicate that short-crested breaking waves are a significant source of vorticity in the surfzone, and likely control surfzone eddy diffusivities when alongshore currents are weak. Thus, the effects of individual breaking waves should be included in numerical models of the surfzone.

We hypothesize that the structure of the incident wave field controls the length of breaking crests and thus the magnitude of vorticity and the eddy diffusivity. Our remote imaging of surfzone breaking waves at an inlet and a beach during the summer of 2012 will be used to examine the connection between surfzone eddies and the length of breaking crests, and to determine if it is possible to estimate the contribution of short-crested breaking to surfzone eddy diffusivities from remote sensing.

RELATED PROJECTS

The remote sensing images of New River Inlet were taken in conjunction with the RIVET DRI and MURI projects, and will be compared with in situ data. A goal of our work to provide recommendations on the inclusion of short-crested breaking physics to numerical modeling studies of the inlet.

PUBLICATIONS

Clark, D.B., S. Elgar, and B. Raubenheimer, Vorticity generation by short-crested breaking waves, *in review at Geophysical Research Letters.*